Experimental investigation of the spatial and temporal characteristics of the 60 GHz radio propagation within residential environments

Sylvain Collonge, Gheorghe Zaharia, Ghais El Zein

EXPERIMENTAL INVESTIGATION OF THE SPATIAL AND TEMPORAL CHARACTERISTICS OF THE 60 GHz RADIO PROPAGATION WITHIN RESIDENTIAL ENVIRONMENTS

S. Collonge, G. Zaharia, G. El Zein

Institut d'Electronique et de Télécommunications de Rennes
IETR/INSA, 20, Av. des Buttes de Coësmes – CS14315
35043 Rennes Cedex, France

ABSTRACT

The 60 GHz frequency band appears to be very promising for wireless multimedia services in the next years. Reasons of this interest are partly due to the large available bandwidths, and to the important power loss caused by the free space attenuation and the propagation through walls, which permits the reuse of the same frequency even in the next floor of the same building.

In France, a national research project, RNRT COMMINDOR, studied new high data rate radio communication systems (155 Mbps), for residential environments. This study has begun by the characterization of the propagation channel at 60 GHz.

In this paper, we present a spatial and temporal characterization of the 60 GHz indoor radio channel. Measurements campaigns have been conducted by the Institute of Electronic and Telecommunication of Rennes (IETR). The results indicate the necessity to introduce a form of diversity in order to guaranty a high data rate link even under NLOS (non line of sight) conditions. We suggest to use the angular diversity of the 60 GHz channel.

1. INTRODUCTION

The congestion of spectral resources and the need for higher data rates lead to explore new frequency bands higher and higher in the electromagnetic spectrum. This frequency elevation goes with a rise of the power loss, which is interesting for wireless local area network (WLAN) in term of frequency reuse.

These future very high data rate networks (more than 100 Mbps) are often referred to as "Fourth Generation" (4G) Telecommunications [1] or even more.

The French research project "COMMINDOR" has studied the feasibility of high rate (155 Mbps) and short range wireless communication network at 60 GHz. Interconnection and control of multimedia equipment are among the possible applications.

The design of an efficient network requires a good knowledge of propagation phenomena. The waves behavior depends on many parameters, such as antennas (beam-width, gain, polarization), physical environment (furniture, materials) and human activity. These parameters are particularly important at 60 GHz. One of the first questions we had to answer concerns the feasibility of a network covering several rooms.

For these reasons, the IETR, one of the COMMINDOR partners, has been studying the 60 GHz channel for the last 2 years. The aim of this publication is to present some major results of two measurements campaigns in residential environments.

The paper is divided into four parts. First the measurement equipment are described. Then the measurement environments and scenarios are presented. The third section explains the measurement processing and describes the main propagation characteristics. Finally, the major results obtained during these campaigns are discussed.

2. MEASUREMENT EQUIPMENT

2.1 Channel sounder

The channel sounder used during our measurement campaigns, developed by the IETR [2], is based on the sliding correlation technique, otherwise known as the Cox technique. Its temporal resolution is 2.3 ns, which means that two paths separated from more than 70 cm can be correctly discriminated. The observation window can be chosen up to 1 µs. As the sliding factor is also adjustable, the measurement duration of the impulse response can be adapted to the temporal variations of the channel. In this way, our sounder can observe Doppler shifts up to several kHz. The relative dynamic is 40 dB, and the transmitted power 0 dBm.

2.2 Antennas

Two kinds of antennas were used during the measurement campaigns: a horn (gain: 22.4 dBi, 3 dB aperture: 12°) and a patch (gain: ~ 3 dBi, 3 dB aperture: 60°). The patch antenna was used for the transmission (Tx antenna), and both the patch and the horn were used for the receiver (Rx antenna). Measurements were done in linear polarization (vertical and horizontal).

The Rx antenna is mounted on a motorized system for a fine antenna positioning in the horizontal plan (versus X and Y axis). This system also controls the azimuth pointing of the Rx antenna. As shown in [3, 4], due to this positioning system, small scale phenomena can be analyzed and determination of angles of arrival is therefore possible.

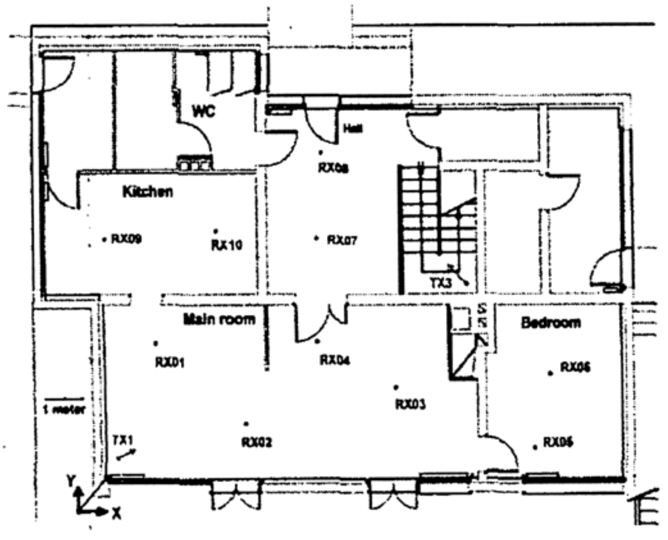
3. MEASUREMENT CAMPAIGNS

3.1 Environments

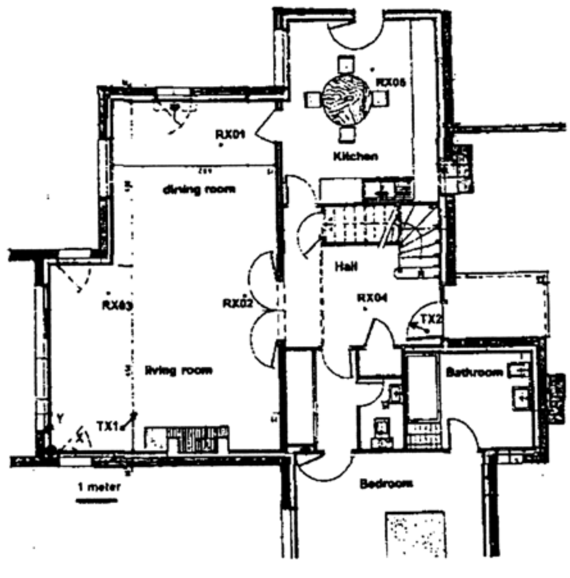
Two residential houses were chosen for measurements. The first one, designed as "C.L.E." in the rest of this paper, can be qualified as "atypical": it is a leisure center for children. The dimensions of the first floor are 13×8×2.9 m. The second one (called "House" afterwards) is an inhabited house, with typical furniture and materials for walls (breeze-block, brick, plasterboard), floors (tiles, carpet), doors, etc. There are several large windows, a fireplace, wooden stairs. The dimensions are 10.5×9.5×2.5 m. Both the *CLE* and the *House* have a second floor.

3.2 Measurement scenarios

The Tx antenna is placed in a corner of the main room, at a height of 2.20 m in the *House*, and 2.50 m in the *CLE*. It is slightly tilted toward the floor (-15° in the *House* and –20° in the *CLE*), to illuminate the whole room at best. The chosen corner is the one for which we can hope the best possible coverage of the other rooms of the floor.



a) *C.L.E*



b) *House*

Figure 1. Site maps with Tx and Rx locations.

The Rx antenna is placed in different positions, in the same or in an adjacent room, at a height of 1.20 m, which is about the height of a computer on a desk. Nine positions (4 LOS and 5 NLOS) have been studied in the *CLE*. In the *House*, five positions have been considered (2 LOS, 3 NLOS). Figure 1 shows the map of each house and the antenna locations during the measurements.

4. DATA PROCESSING

The channel sounder evaluates the time-varying channel impulse response $h(\tau,t)$, where τ represents the delay and t the time. After a correction by egalization on the unprocessed data, a measurement noise level of about –120 dBm is determined for the computation of the dynamic range.

From the impulse responses, several propagation characteristics are computed: attenuation, delay spread (τ_{rms}), 90% delay window, coherence bandwidth at 75%.

Attenuation is defined as the difference between the power at the input of the Tx antenna and the power at the output of the Rx antenna. Antennas are parts of the channel, since they influence its behavior due to their radiation pattern.

The delay window at X% evaluates the channel delay spread. It is the time interval containing X% of the power of the impulse response. Moreover, this window is centered: the 100-X other percents are equally distributed between the two window-sides.

The coherence bandwidth at 75% (Bc_{75}) reflects the correlation between two spectral components of the channel transfer function, computed as the Fourier transform of the impulse response. Due to the limited bandwidth of the channel sounder, the maximum observable coherence bandwidth is 250 MHz.

5. RESULTS

5.1 Geometric considerations

An example of an angular measurement is shown on Figure 2.

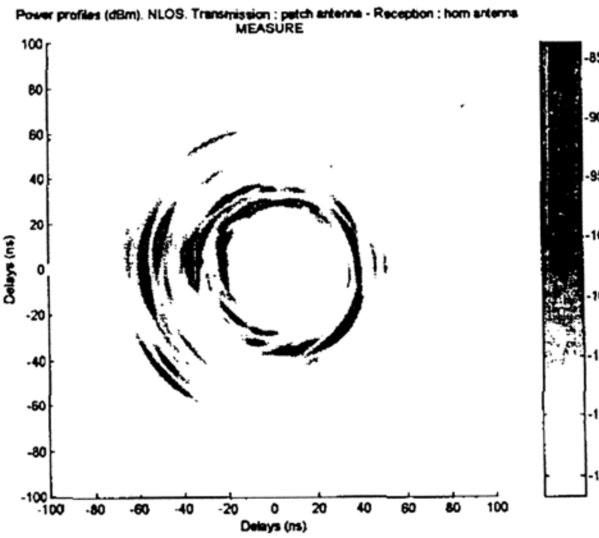


Figure 2. Power profiles for RX04 in the House.

It is the representation of the received power profiles with respect to the azimuth angle of the Rx antenna. Similar diagrams can be obtained for the other channel characteristics. The superposition of these diagrams with the site map permits to understand better the waves propagation through the considered channel.

First, we observe that, for LOS conditions, the major part of the received energy comes from the direct path, but also from the first order reflected paths. Globally, higher orders of reflection are less significant, as can be seen on Figure 3.

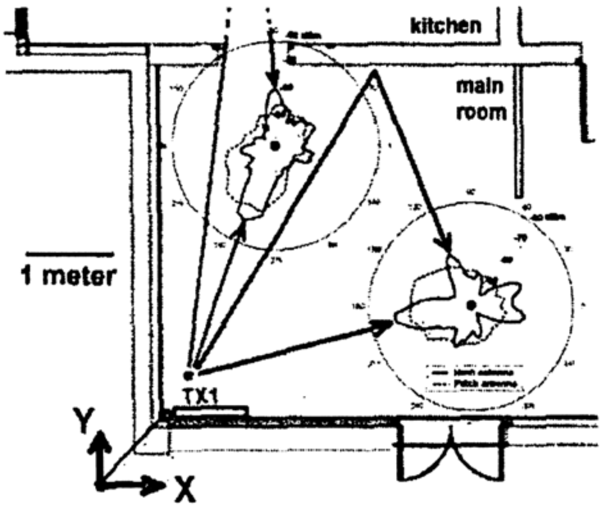


Figure 3. Received power for RX01 and RX02 in the C.L.E.

In a NLOS case, when Tx and Rx antennas are in different rooms, we can notice from the maps (Figures 4 and 5) that the waves use "radio electric openings" such as opened doors. This can be particularly seen for a horn antenna at the reception: received power peaks are pointed towards the doors or towards the direction of a reflected path passing through the doors.

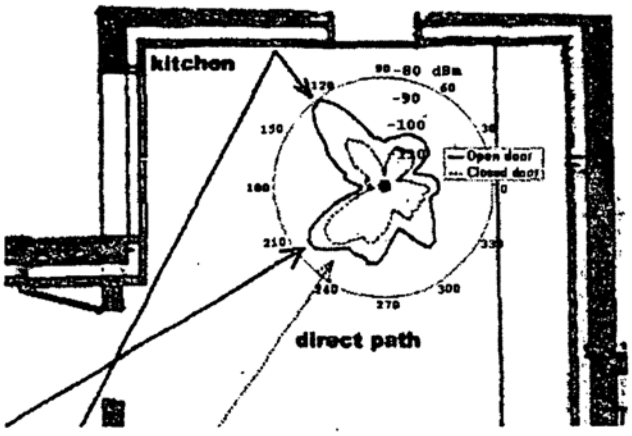


Figure 4. Received power for RX05 in the House.

This behavior is confirmed by measurements done with closed doors. A mean difference of 11.8 dB is found between the two cases. This result is included into the interval indicated in [5]: plus 7 to 15 dB of attenuation when the doors are closed.

The direct path is generally very attenuated by wall penetration and his contribution is insignificant. The angular power distribution heavily depends on the geometric configuration of each situation, and in particular, on the vicinity of the reception antenna. Among the NLOS measurements, two general behaviors can be distinguished: either one or two dominant directions of arrival exist (Figure 4), either the angular power distribution is scattered on a large angular sector, as shown in Figure 5. Similar observations can be find in [5].

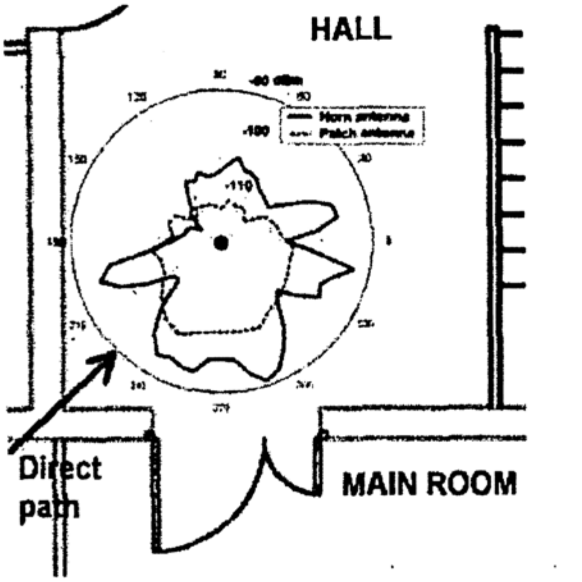


Figure 5. Received power for RX07 in the C.L.E.

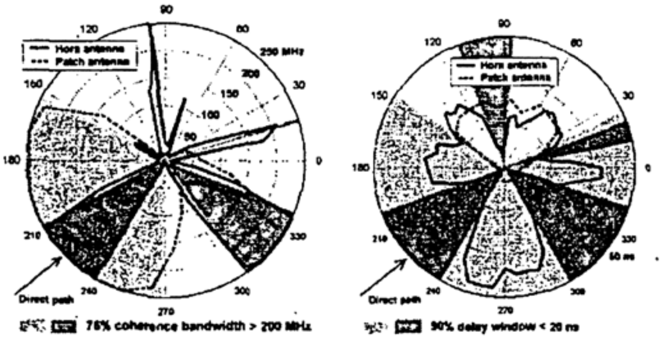
5.2 Comparison Horn/Patch

It has already been shown that the temporal dispersion of the channel is stronger when antennas have larger aperture [6]. Therefore, a directive Rx antenna can reduce the frequency selectivity of the channel but it must be correctly pointed.

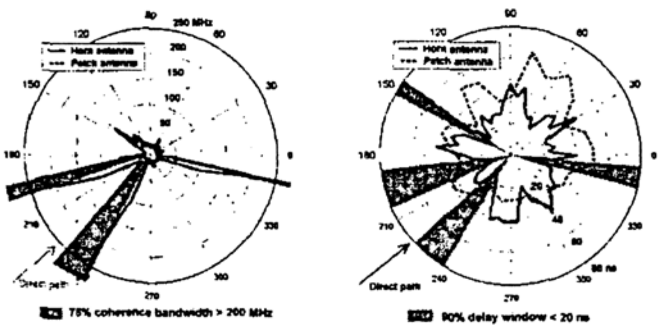
Our measurements show that for LOS situations, and for a Rx antenna pointed to Tx, a rotation of the Rx antenna of 0.5 to 2 times its –3 dB aperture causes a deep degradation of broadband characteristics such as Bc_{75} (from > 200 MHz to < 50 MHz). This observation is true for the horn and for the patch, as we can see on Figures 6.a) and 6.b). So, a patch antenna can uniformly cover, around the arrival direction of the direct path, a larger angular sector than the horn. For the horn, the existence of reflected waves assures good frequency-selectivity characteristics in other directions than the direct path (this is not true for the patch antenna). Considering the whole set of measurements, the Bc_{75} is greater than 250 MHz in 32% of the cases for the patch, and only in 17% for the horn.

Nevertheless, under NLOS conditions, the patch does not allow as good performances as the horn, in term of frequency selectivity. As shown on Figures 6.c) and 6.d), only the horn antenna can realize a link with good frequency selectivity characteristics, on few sharp angular sectors. These angular sectors generally have the size of the -3 dB horn aperture, and their directions are difficult to predict since these directions strongly depend on the channel topology. The results show that

Bc_{75} > 250 MHz in 7.8% of the cases for the horn, and only in 2.9% for the patch.



House: a) LOS – Bc_{75} – RX02 b) LOS - $F\tau_{90}$ – RX02



CLE: c)NLOS – Bc_{75} – RX07 d) NLOS - $F\tau_{90}$ – RX07

Figure 6. Comparison Horn/Patch of the angular coverage for two broadband characteristics (Bc_{75} = 75% coherence bandwidth, $F\tau_{90}$ = 90% delay window).

5.3 Human activity

Measurements on time-varying channel have also been done in the two depicted environments.

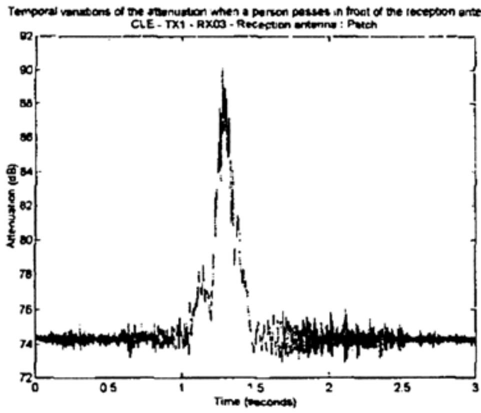


Figure 7. Time variation of the attenuation

This study is more detailed in [4]. We briefly present one of the measurement scenarios: the shadowing of the direct path when a person walks between the antennas. This situation has been tested for the reception position RX03 in the *CLE*. The Rx antenna was pointed towards the transmitter TX1. Acquisition is done during 5 s, with a sampling step of 1 ms. Figure 7 illustrates the moment when a person passes in front of then Rx antenna at a distance of 1 m.

The movement speed is about 1 m/s. The shadowing by the human body increases the attenuation by 17.3 dB above its mean. Attenuation is greater than 5 dB above its mean for 0.17 s and the Bc_{75} decreases from 250 MHz to less than 50 MHz. This outage duration is long compared to the considered data rates.

6. SUMMARY

Measurements at 60 GHz have been presented for two residential environments. An angular characterization of the channel has been performed in order to analyze the angle of arrival of the multipath components. The dominant contribution of the direct path has been unlighted for LOS situation. In the case of a directive reception antenna, thanks to first-order reflected waves, it is possible to maintain good propagation characteristics (high coherence bandwidth and low delay spread) in other directions. In NLOS situations, the horn gain and angular selectivity are necessary to reduce the temporal dispersion of the channel.

A clear disadvantage of directive antennas is the need for an adequate pointing. The use of smart antennas that are able to turn their beams themselves, can be a solution.

In the same time, we have to think about shadowing problems caused by human activity. The use of an angular diversity can resolve these problems: when a path is shadowed, another one, coming from another direction, is possibly free.

7. REFERENCES

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